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ABSTRACT

An analysis of science teacher's knowledge of specific biology and physics topics and the effects of this knowledge on their planning for instruction and on simulated teaching are discussed in this report. Six experienced secondary school teachers participated in the study. Each teacher's knowledge of a biology topic and a physics topic was assessed using summary free recall, concept-map line labeling, and sorting tasks. The knowledge varied on four dimensions: (1) knowledge of topic; (2) knowledge of other discipline concepts, principles, and topics; (3) knowledge of conceptual schemes; and (4) knowledge of approaches or ways of connecting the topic to other topics in the discipline. The study results suggested that prior teacher knowledge of subject matter contributed to the transformation of the written curriculum into an enactive curriculum. Appendices include the physics and biology knowledge schemata. (ML)

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EFFECTS OF SUBJECT-MATTER KNOWLEDGE IN THE TEACHING OF BIOLOGY AND PHYSICS

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by

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ABSTRACT

The importance of teachers' knowledge of the subject-matter content they are teaching has often been noted. We have little evidence, however, of the specific effects of a teacher's knowledge of a topic and how he or she teaches that topic. The aim of the research presented here was to describe science teachers' knowledge of specific biology and physics topics and trace the effects of this knowledge on their planning for instruction and on simulated teaching.

Six experienced secondary-school teachers--three specializing in physics and three in biology--participated in the study. Each teacher's knowledge of a biology topic and a physics topic was assessed using summary free recall, concept-map line labeling, and sorting tasks. A small number of schemata described each teacher's subject-matter knowledge. The knowledge varied on four dimensions: (a) knowledge of topic; (b) knowledge of other discipline concepts, principles, and topics; (c) knowledge of conceptual schemes; and (d) knowledge of approaches or ways of connecting the topic to other topics in the discipline.

The teachers planned instruction in the biology and physics topics based on content in textbook chapters provided by the investigator. The planning took place in thinking-aloud sessions, which were audiotaped and transcribed. The influence of the teachers' prior subject-matter knowledge was evident in their modifications of textbook subject-matter content and through their use of explanatory representations. Simulated teaching consisted of a critical-incidents technique. The effects of subject-matter knowledge were apparent here through the teachers' use of evaluative structures and responses to critical incidents.

INTRODUCTION

There is a need to study teacher knowledge, and subject-matter knowledge in particular, due both to the importance of this information in informing the current debate on teacher education and certification and to the relative neglect of this area by researchers interested in research on teaching. An adequate conceptualization of teaching should accommodate to the fact that teaching is an interaction between at least three elements--teacher, student, and subject-matter. However, subject-matter has been curiously neglected by the successive traditions in the study of teaching.

In spite of the fact that it is intuitively obvious that one needs to know what he or she has to teach to adequately teach it, the need for rich subject-matter knowledge has often been challenged. The oldest tradition in the study of teaching, the presage-product paradigm, has failed to show high correlations between subject-matter knowledge and student achievement (Byrne, 1983). Within the process-product paradigm it was impossible to study unobservable entities such as teacher knowledge. The teacher cognition program has focussed on describing process rather than content in spite of the growing evidence in cognitive psychological research about the importance of the specific knowledge that the individual brings to bear in intellectual problem-solving. Only a small portion of the studies on teacher cognition addresses teacher knowledge, and a much smaller portion addresses subject-matter knowledge (see, for example, Clark and Peterson, 1985). Shulman (1985) recently commented: "Where the teacher cognition program has clearly fallen short is in the clarification of teachers' cognitive understanding of subject-matter content and the relations between such understanding and the instruction teachers provide for students" (p. 98).

Recently, there has been a budding interest in teacher subject-matter knowledge. Leinhardt and her colleagues (e.g. Leinhardt, 1983; Leinhardt & Smith, 1984) carefully describe the subject-matter knowledge of teachers. Anderson and Smith (1983) also trace the effects of subject-matter knowledge. However, both groups use the same data both to infer teacher knowledge and to describe its effects. Shulman and his colleagues (Shulman, Sykes, & Phillips, 1983) also study subject-matter knowledge, but are more interested in the growth of teacher knowledge and less in its effects on teaching. The need to first describe teacher understanding of subject-matter and consequently trace the effects of this understanding on teaching activities has still not been met.

DESCRIPTION OF THE STUDY

Aim of the Study

The purpose of the study was two-fold: to describe science teachers' subject-matter knowledge and to trace the effects of this knowledge on aspects of their planning and simulated teaching. Subject-matter knowledge was defined in the narrow sense to refer to the teacher's knowledge of the discipline--knowledge content and organization. This is both abstract knowledge, such as knowledge of discipline conceptual schemes, and more specific knowledge, such as knowledge of details of a particular topic. Knowledge associated with teaching a specific topic, or what might be termed subject-matter pedagogic knowledge is not described in this paper (see Hashweh, 1985, for detailed study). The aspects of planning and simulated teaching that were deemed important to investigate were those aspects that influenced the transformation of the written curriculum into an enacted one, and these aspects are described later in the paper. The

study did not aim to formally test hypotheses, but to start an exploration of the relations between subject-matter knowledge and teaching.

Subjects and Design

Six experienced secondary-school science teachers participated in the study--three specializing in physics and three in biology. (The physics and the biology teachers are called in this paper PA, PB, PC and BA, BB, BC). The study was designed to assess each teacher's knowledge of two topics, one from physics and the other from biology, and then to assess their pre-active and simulated interactive teaching of each of the two topics. This made it possible to "experimentally" vary the subject-matter "variable" and to trace the effects of these variations on teaching. By permitting assessment of each teacher's knowledge and observation of his or her teaching within areas of low and high expertise, the design allowed each subject to become his or her own control -- a within-subject as well as between-subject design.

The two topics used in the study were levers and photosynthesis. Many factors contributed to choosing these two topics. Both can be treated at different levels, and can be related to other discipline entities in different ways. It is also possible to have different levels of understanding of each topic. Students could also have different preconceptions (or misconceptions; the terms are used interchangeably in the paper) associated with these topics.

Procedure

Each teacher participated in three sessions, the total duration of which ranged from four to six hours. The sessions were distributed over a period of two to three weeks. During the first session the

teacher's knowledge of each of the two topics was assessed using the Subject-Matter Knowledge Tasks described below. Each teacher was asked first about the topic he or she was familiar with. For each topic, the tasks were given in the following order: Free-Recall, Concept-Map Line-Labeling, and Sorting. This ordering allowed the teachers to exercise more freedom at the beginning in selecting the content of knowledge they discussed, and in imposing a structure on this knowledge. The more focussed questions followed.

The second session aimed to describe the teacher's preactive and simulated interactive teaching of the familiar topic. The teaching of the topic of low expertise was assessed during the third and final session. The instruments used in these two sessions were the Biology and Physics teaching tasks described below. In each session the teacher was first provided with a textbook chapter dealing with the topic, and asked to plan while thinking aloud. More directed questions about planning were asked at the end of this part of the session. Finally, the teacher was asked to respond to a set of "critical incidents" to assess the teacher's simulated interactive teaching of the topic.

All sessions were audiotaped and transcribed. The transcripts were subjected to content analysis. The aim of the analysis was to search for patterns that characterize a) subject-matter knowledge, b) preactive and interactive teaching, and c) relations between a and b. The analysis consisted of a helical process of inducing patterns and categories, examining the transcripts for confirmatory purposes, inducing new patterns and categories or modifying old ones, and repeating the confirmatory part of the cycle.

Instruments

A. Assessment of Subject-Matter Knowledge

Three tasks were used for assessing subject-matter knowledge of each of the two topics.

Task One - Summary Statements: The teachers were asked to summarize what they knew about the topic in a few minutes. They were asked twice if they had more details to add. They were asked to relate the topic to other ideas in the discipline, to other areas of knowledge, and to the students' experiences. They were also asked to summarize what they knew about three or four other related disciplinary concepts or ideas.

Task Two - Concept-Mapping: The teachers were given a list of 20 terms in the physics task and 17 terms in the biology task. They were asked to draw a map by connecting the concepts to each other and to label the connecting lines. After the teacher decided on a final organization, he or she was asked to "walk the researcher through" the map, or to explain it.

Task Three - Sorting: The teacher was given 11 mechanics physics problems in the physics task and 9 "exam questions" in the biology task. The teacher was asked to sort the problems or questions into groups depending on the common ideas or concepts that they require for answering them. The physics problems were designed to vary on two dimensions, their "surface" and their "deep" features. All the biology "exam questions" included photosynthesis but focussed on relating it to particular biology concepts.

B. Assessment of Teaching

The second set of instruments aimed at assessing the teachers'

preactive and interactive teaching of the two topics. The planning task for each topic required the teacher to plan while thinking aloud to teach the topic using a textbook chapter dealing with the topic. The textbook chapters were chosen from two popular general science and biology textbooks. A context for the task was provided by asking the teacher to imagine that he or she had to replace an ill colleague. Information about the grade level, the abilities of the students, and the material already covered was provided.

At the end of the thinking-aloud part of the session the teacher was asked eight questions about evaluation plans and possible exam questions, changes for bright students and for less time, representations used, use of student prior knowledge, student difficulties with the topic, and long-range plans.

The interactive teaching was simulated and assessed by orally describing to the teacher a set of critical incidents that could occur during the teaching of the topic, and asking the teacher for his or her reaction to the incident and for how he or she would respond. Twelve physics and nine biology critical incidents were used. The incidents consisted of vignettes portraying situations where a student response could reflect a preconception, situations that "invited" the teacher to discuss unplanned ideas from the discipline or the same topic in greater detail, situations that revealed a student's insightful comment, and situations that involved a general class difficulty.

RESULTS

Subject-Matter Knowledge

In this part of the paper the data from the first session are presented and interpreted to describe subject-matter knowledge. Schemata were constructed to describe each teacher's knowledge, and a small number was found to account for this knowledge. It should be pointed out that these schemata are considered, in this study, as a convenient form of describing the knowledge discussed by the teacher during the course of the session. The schemata are a model of the teacher's knowledge of subject-matter, and are not meant to represent the internal knowledge organization in any teacher's memory. The teachers' knowledge in physics and in biology are separately presented before a synthesis is offered.

Physics Knowledge

Two topic schemata and at least four other physics shemata were identified. The two topic schemata were Lever and Simple Machines, while the four other physics schemata were Motion/Force,Work/Energy, Vectors, and Torques. Appendix A shows the lever schemata of teacher PA. The physics teachers,in general, had richer topic and non-topic physics schemata, richer in that the schemata contained other subschemata each of which was quite detailed.

Of the four non-topic schemata, the most important were Force/Motion and Work/Energy. These are two high-order physics schemata that are very basic in physics. Indeed, Classical Mechanics could be reduced to these two conceptual schemes -- the motion/force approach or the work/energy approach. The three physics teachers invoked both these schemata in responding to the summary statements and the concept mapping tasks. These

teachers used the two basic schemata to organize their knowledge of physics and the topic. In contrast, none of the biology teachers had rich knowledge of these schemata or could use them to organize their knowledge.

The physics teachers' knowledge seemed to be quite stable. When given the sorting task the physics teachers used the Force/Motion and the Work/Energy schemata to categorize the physics problems, while the biology used the surface features of the problems, that is, categorized them as levers, pulleys, and ramps problems.

The teachers' knowledge was also analyzed for teacher preconceptions and knowledge inaccuracies. While almost every teacher had preconceptions or knowledge inaccuracies, the greatest number was held by the two least knowledgeable biology teacher (the third biology teacher had better physics knowledge due to his experience in teaching general science). These two teachers had preconceptions about work, simple machines, efficiency, mechanical advantage, and some other concepts. In general, their preconceptions corresponded to the common-sense or the non-technical usage of these terms. Work, for example, referred to physical activity and simple machines referred to uncomplicated machines. In addition to using the term work to refer to physical activity, biology teacher, BC, failed to differentiate between work and force. While discussing simple machines he commented:

> I guess the simplest of all machines would be parts of your body ... It's a lot easier to go down, to bend your knees to lift an object. You can lift more weight than it is by going over like this and pulling up. It's less work involved doing that.

Notice how "easier" in the second sentence is interpreted as "less force needed" in the third. "Less force" becomes "less work" in the final sentence.

Biology Knowledge

It was found that three topic schemata could account for the topic knowledge: Photosynthesis Overview, The Light Reactions, and The Dark Reactions. Appendix B shows the Photosynthesis Overview schema of biology teacher BA. Nine schemata, used by different teachers in different frequencies, could account for the non-topic biology knowledge invoked by the teachers in responding to the tasks. These schemata were: Respiration, Food/Energy, Other Ecological Relations, Synthesis, Food and Nutrition, Chemistry/Energy, Plant Transport Systems, Leaf Structure, and Evolution (for the complete description, see Hashweh, 1985).

The most important difference between physics and biology teacher knowledge of the topic was in knowledge details. Two of the biology teachers had schemata of the Light and Dark Reactions while none of the physics teachers had this detailed knowledge of the photosynthesis processes. The physics teachers also invoked less non-topic biology knowledge. They had only two out of nine other biology schemata. These were Food/Energy and Other Ecological Relations. Each biology teacher had these two schemata plus two more: Respiration and Synthesis. In addition, the biology teachers used different combinations of the remaining five schemata.

The fact that the biology teachers made connections to different combinations of other biology schemata contrasts with the finding that all physics teachers related the lever topic to two physics schemata. That is, whereas one structure or approach characterized the physics teachers' knowledge, no single approach could be found to characterize the biology teachers' knowledge.

However, although no single structure characterized the biology

teachers' knowledge, approaches were identified that accounted for two of the three teachers' knowledge. BA used a molecular/energy approach, with a smaller emphasis, with an ecological approach. What characterized the molecular/energy approach is the emphasis on the chemical and energy-related aspects of biological processes at the cellular level. The most important ideas are that energy is needed to make complex molecules, that energy is released when complex molecules are broken down, and that chemical energy is stored in bonds. These ideas, presented in BA's Chemistry/Energy schema influenced the rest of her schemata. The function of photosynthesis, for example, was described at the molecular level: to trap energy in chemical bonds. None of the other teachers described the function of photosynthesis at this level. BA's description of the photosynthesis process was also molecular: attaching molecules to one another and trapping energy in chemical bonds. She also related cellular respiration to photosynthesis through the use of this molecular/energy approach. She described respiration as a process of breaking down the chemical bonds to liberate the energy for cell activity. She also used the same approach to relate photosynthesis to Food/Nutrition. Finally, the energy part of BA's schema was exemplified in her discussion of energy wastage in food chains.

The second biology teacher, BC, used a traditional macro plant-structures approach, in addition to using ecological themes and, to a lesser extent, evolutionary ones. The third biology teacher, BB, made the least number of connections to other biology schemata. No clear structure was identified in his knowledge.

Analysis of the data for preconceptions and knowledge inaccuracies revealed that both groups of teachers held preconceptions and in-

accuracies, but the physics teachers held a bigger number of them. For example, two physics teachers held the same preconception about cellular respiration: both seemed to relate it to an excretory function. The third thought that respiration was synonymous with breathing. In both cases, the physics teachers used the common-sense meaning of the term, reminding us of the analogous use of physics terms by biology teachers discussed earlier.

Synthesis and Discusssion

The teachers tended to have a superior knowledge base and structure within their field of expertise. Within their field of expertise, the teachers tended to have a) more detailed topic knowledge; b) more knowledge of other discipline concepts; c) more knowledge of higher-order principles that are basic to their discipline--discipline conceptual schemes; d) and more knowledge of ways of connecting the topic to other entities in the discipline--approaches to the topic. The physics teachers had two basic higher-order schemes that they related to the topic, thus giving their knowledge a unified organization or approach. However, one physics teacher seemed less inclined to relate the topic to one of these schemata. The biology teachers related the topic to a varying number of other biology schemes. In two cases a specific organization or approach characterized the way of relating the topic to the other schemata. In the third case, no organization was detected.

The fact that there were two higher-order physics schemata that were related to the topic by physics teachers while no corresponding schemata were used by the biology teachers might be explained by the nature of the physics and biology non-topic schemata that were identified. The two physics schemata corresponded to basic higher-order principles in

classical mechanics, while in biology no corresponding small number of higher-order schemata, or conceptual schemes, can describe the structure of the discipline. Hence, the biology teachers chose different combinations reflecting individual approaches. It should be remembered that the Biological Sciences Study Committee, unable to identify one structure for biology, came out with three sets of textbooks in their project, each emphasizing a certain approach.

Going back to the two physics schemata, it should be pointed out that the findings are corroborated by previous studies. The two schemata constructed inductively in this study correspond to the physics schemata described in one previous study (Larkin, 1983) and are in close agreement with the findings of another (Chi, Feltovitch, and Glaser, 1981).

Finally, the findings reported in this part of the study suggest that it might be useful to compare teacher subject matter knowledge on each of the following four dimensions:

1. Knowledge of topic.
2. Knowledge of other discipline concepts, principles, relations.
3. Knowledge of discipline higher-order principles or conceptual schemes.
4. Knowledge of approaches or of different ways of relating the topic to other discipline "entities" whether they be other topics, concepts, principles, or conceptual schemes.

Effects of Subject-Matter Knowledge

In this section of the paper, the effects of subject-matter knowledge on teacher planning, will be presented through tracing the effects of prior knowledge on the transformations made in chapter organization and content. The teachers' plans will also be analyzed for the activities planned. The effects of teacher prior preconceptions and knowledge inaccuracies will be separately examined.

The effects of teacher subject-matter knowledge on interactive teaching will be presented through tracing the effects on the evaluative structure used by the teachers, and their responses to the Critical Incidents Tasks. Finally, the explanatory representations used by the teachers will be separately presented and discussed.

Knowledge Organization

During the physics planning task the teachers were given a chapter from a popular ninth-grade general science textbook (Barman, C.R., Rusch, J.J., Schneiderment, M.O., & Hindin, W.B., 1982). The chapter was organized around the theme, "systems help make work easier." Four systems (ramps, levers, pulleys, and gears) were discussed, emphasizing in all cases that systems allow a gain in force. In the only system where work was discussed, the discussion gave the impression that a gain in work was achieved also.

An examination of the teachers' plans revealed that the two teachers with minimal physics knowledge, BA and BC, followed the textbook's structure quite closely. Both of them started the chapter by defining machines as "things that make work easier," and both related this idea to the systems they discussed. One of them explicitly discussed machines as decreasing work.

In contrast, the three physics teachers and the topic-knowledgeable biology teacher rejected the chapter's structure. The topic-knowledgeable biology teacher failed to offer an alternative structure, while the physics teachers offered alternative organizations. Two of them used an approach that used the work/energy and the functions-of-machines themes, while the third used the work/energy theme only. Thus, the physics teachers related the topic to an important discipline conceptual scheme.

The chapter used in the biology planning session was on cell energy, and it was taken from a popular tenth-grade biology textbook (Otto, J.H., & Towle, A., 1973). The organization or theme of the chapter was very difficult to detect. The theme (that in photosynthesis the sun's energy is changed to chemical energy, and in cellular respiration the chemical energy stored in glucose is released for use by the cell) was provided only in the first section of the chapter and next to two bold-typed sentences that distracted the reader from the theme.

The three physics teachers failed to understand the chapter's theme. It was especially hard for them to understand the theme because of an important feature of their prior subject-matter knowledge that differentiated them from their biology colleagues. They did not know what the function of respiration was. Lacking this knowledge and not reading the first section of the chapter carefully, they could not understand why topics like photosynthesis, respiration, and fermentation are included in the same chapter. The physics teachers planned to teach the topics but failed to offer a theme or structure for the content they planned to teach.

In contrast, two of the biology teachers detected and understood the chapter's obscure structure, while it was not clear if the third

teacher understood or detected the theme. BA,the teacher whose prior subject-matter knowledge approach coincided with the chapter's offered a plan explicitly emphasizing this structure. (It should be noted that her approach was previously described as cellular and emphasizing molecular/energy aspects).

The second biology teacher, BB, understood the chapter's theme but failed to offer a structure in the knowledge he planned to teach. It should be recalled that his prior subject-matter knowledge had lacked a structure also. The third teacher, BC, seemed not to detect the chapter theme. He offered two alternative themes, the macro plant-structures and the ecological approaches, to organize the knowledge he planned to teach. The same approaches were previously found to characterize his prior subject-matter knowledge.

In summary, when the teachers were given a chapter with a detectable but meaningless (in disciplinary terms) theme, the unknowledgeable teachers closely followed the chapter structure while the knowledgeable teachers rejected the theme. When the teachers were given another chapter with a theme that was acceptable from a disciplinary point of view but that was not easily detectable, the unknoledgeable teachers were not able to detect the theme. In the first case the knowledgeable teachers offered an alternative structure, while in the second case they either used the chapter structure or offered an alternative one.

Prior knowledge affected the transformation of chapter organization in two ways. Only knowledgeable teachers rejected a meaningless theme or detected a subtle one. Secondly, knowledgeable teachers used the chapter structure only when it coincided with their prior subject-matter knowledge content and approach.

Chapter Content

The teachers' plans were analyzed for deletions of chapter concepts or for additions of concepts. An examination of the teachers' physics plans showed that, in general, teachers plan to teach the concepts found in the textbook. However, an important exception appeared. All four knowledgeable teachers deleted the concept that "machines help do work," while the two least knowledgeable teachers planned to teach this concept. The deleted concept contradicted the knowledgeable teachers' prior knowledge and the theme used in planning by three of them. The teachers also deleted some other concepts that, on the basis of their prior knowledge, were deemed unimportant.

The teachers also added concepts to the ones found in the chapter. A factor that contributed to the selection of concepts was the approach or the theme used in planning. The three physics teachers emphasized a work/energy approach and, hence, either totally neglected to introduce ideas related to a force/motion approach (as PB and PC did) or used some of these ideas in a limited manner and with caution (as PA did in relating the concept of torques to levers).

An examination of the teachers' biology plans also revealed that the majority of modifications in chapter content could be traced back to the teacher's prior subject-matter knowledge and approach. The three biology teachers deleted the details of the light and dark reactions in photosynthesis that they themselves had trouble remembering. Both BB and BC, who did not subscribe to a molecular/energy approach, deleted the concepts related to the theme of the chapter. Both also did not plan to discuss the function of photosynthesis; the function is not important if the energy theme is not used.

Content additions were also traced back to teacher prior subject-matter knowledge. As an illustration, BC and BA planned to relate photosynthesis and respiration through the use of the ecological concept of cycles. Only the two of them had emphasized this relation in responding to the previous subject-matter knowledge tasks. Both were previously described as having partly ecological approaches.

In summary, in both biology and physics planning tasks the teachers planned to teach most of the concepts used in the textbook. However, there were also important additions and deletions partly affected by the teacher's prior subject-matter knowledge content and approach. Teachers tended to delete "details" they themselves could not remember and concepts that were not essential for the theme used in planning. They added many of the concepts they knew, especially those that were either consistent with or easily related to the theme used.

Activities in the Teachers' Plans

The physics chapter included six activities. Each knowledgeable teacher modified two or three of these activities, while the two least knowledgeable teachers planned to follow the six activities closely. The modifications can be traced to the teachers' prior subject-matter knowledge and approach used. The two most knowledgeable physics teachers decided to discard the gears activity. The reason why they had the option of discarding it was the fact that the activity was not essential for developing the theme they were using. They had already discussed the work/energy principles and the functions of machines with respect to three other machines or systems. The least knowledgeable teachers, on the other hand, lacked this theme. They assumed that knowledge of every system

was important for its own sake and, thus, did not believe, in my opinion, that they had the option of discarding that activity, or any other activity.

The knowledgeable teachers also expanded or enriched some of the activities. Many enrichments were made to emphasize the theme used by the teachers in planning. Thus, the three physics teachers enriched the ramp activity to include work relations. Other enrichments were made because the teacher had a rich knowledge schema related to the activity. Two teachers, for example, expanded the lever activity to include the quantitative relation, $F_1r_1 = F_2r_2$. The findings about activity enrichment support the findings about concept additions reported earlier. In both cases, the additions reflected the teachers' prior knowledge and themes used in planning.

The biology chapter did not include any activity. The physics teachers, in this situation, could not generate any activities in their plans. In contrast, the biology teachers planned many activities and demonstrations. These activities reflected the teachers' prior subject-matter knowledge and approach. Most of the activities reflected the themes used by the biology teachers in their planning. For example, BA described four activities and demonstrations. One, the terrarium demonstration, illustrated the ecological concepts of balance and cycles, emphasizing her ecological theme. Two other activities illustrated the movement of chloroplasts and the nature of chlorophyll, emphasizing her molecular approach.

To summarize, when activities were provided by the textbook, unknowledgeable teachers followed them closely. Knowledgeable teachers made many modifications that reflected their prior knowledge and approach.

When no activities were provided only knowledgeable teachers could generate activities on their own. The activities reflected the teachers' prior knowledge and approaches.

Effects of Preconceptions and Inaccuracies on Teachers' Plans

An examination of the teachers' physics plans revealed that many preconceptions and knowledge inaccuracies appeared again. Two biology teachers, BA and BC, used their misconceptions about work and functions of machines as themes for the chapter. This was encouraged, of course, by the chapter's theme.

An examination of the teachers biology plans revealed that preconceptions and inaccuracies appear again in the plans, in some cases even though the textbook contained information that contradicted these preconceptions. BC, a biology teacher, repeated his belief that water was an input into the respiration process rather than a by-product. Both physics teachers who held the preconception that the green color or plants was the result of an adaptation process repeated this preconception in their plans. However, PB discovered his mistake while reading a subsequent chapter section that contained contrary information. He was the only teacher who changed his preconception as a result of reading the chapter. PA, the other physics teacher who held the same preconception, and BC whom we have discussed earlier, either did not realize that the chapter offered information contrary to their preconceptions or did not read the particular sections containing this information while planning.

In summary, another feature of the teachers' prior subject-matter knowledge that affected their planning was the preconceptions and inaccuracies that they held. Both knowledgeable and unknowledgeable teachers

had preconceptions and knowledge inaccuracies. Most of these appeared again in planning, in some cases even though the textbook contained information contrary to these inaccuracies.

Effects on Simulated Teaching: Evaluation

An examination of the questions that the teachers generated as exam questions for the physics chapter revealed the influence of subject-matter knowledge. Biology teachers asked questions that were mostly recall questions about topic concepts. For example, BC expected his students to identify the parts of the lever and to know the different classes of levers. The physics teachers, in addition to these questions, asked about other physics ideas that could be related to the topic. For example, PA asked questions about work and energy relations in a ramp system. In addition, the physics teachers asked higher-order questions, questions that required application. PB, for example, asked, "How is driving a boat different from driving a car?" to evaluate if the students could apply the concepts of static and fluid friction. In summary, the physics teachers' questions indicated a greater variety on both content and process dimensions.

An examination of the teachers' responses to the corresponding task for the biology chapter revealed similar effects. The biology teachers used more questions that required non-topic biology ideas or that required the synthesis of textbook ideas. The physics teachers, on the other hand, asked more questions that required direct recall of textbook ideas. The questions of the biology teachers were also consistent with their subject-matter approach. BA asked about energy-releasing and energy-demanding processes, reflecting her energy approach. BC asked about the structure and function of the leaf reflecting his macro plant-structures approach.

In summary, the questions used by the teachers in evaluating student achievement reflected prior teacher knowledge and approach. The unknowledgeable teachers tended to ask questions requiring recall of topic knowledge found in the textbook. The questions asked by the knowledgeable teachers required knowledge not discussed in the textbook, or required the synthesis of textbook ideas. Their questions were at a higher level in terms of the abstractness of the concepts required or the intellectual processes required.

Effects on Simulated Teaching: Critical Incidents

Four types of incidents were used in biology and in physics as described earlier. One type portrayed situations that revealed the probable existence of student preconceptions. The knowledgeable teachers were more likely in these situations to detect student preconceptions and to correct them, while the unknowledgeable teachers failed to detect the probable preconceptions, and reinforced them in some cases.

When a student suggested, in Physics Incident 2, that the efficiency of a lever could be increased by lengthening its lever arms BA, a biology teacher, responded by saying that was a good answer. BC said that that was true, and he gave an example in support of the student's suggestion. He explained that at home he uses a pipe to lengthen his wrench, allowing him to exert more force. He held the same preconception his student had: more efficient means more force.

In contrast physics teacher PA used the example to show that if he follows the student's suggestion and lengthens the lever arm, an increase in force is gained but a loss of distance also occurs, a situation that causes no net gain in work, and, therefore, no gain in efficiency.

Another type of incidents presented the teacher with opportunities to discuss some physics or biology concepts that he may not have planned to discuss. A strong subject matter effect was identified. Two biology teachers used these opportunities to discuss a non-topic biology concept or to discuss a topic concept in more detail, while none of the physics teachers used these opportunities. In the corresponding physics incidents two physics teachers and no biology teacher used these opportunities.

A third type of incidents required the teacher to appreciate a student insightful comment. In the physics incidents, there was a clear effect of prior teacher knowledge. A description of teacher responses to one incident of this type may serve to illustrate this effect.

The incident was designed by using a certain chapter activity (which all teachers planned to use in their teaching) and providing imaginary responses to the questions found in the textbook at the end of the activity. The responses of an imaginary group of students were made up so that the work in was slightly smaller than the work out. This of course, is impossible since there is always some energy lost due to friction. That is, usually the work in should be greater than the work out.

When a student objected to these results saying they are impossible, the two most knowledgeable teachers, PB and PA, immediately realized what he had in mind: the results are impossible because they contradict conservation principles. Both indicated that they would investigate what the students with the wrong results had done in order to determine the cause of the error.

Two of the biology teachers, including BB who had a somewhat adequate Work/Energy Schema, had a different interpretation of the student's

objection. They assumed that the student objected because the work in was only slightly less than the work out. In their opinion, work in should have been much smaller than work out. BB used the previously predicted preconception of confusing work with force: he assumed that the work in should be half the work out. Ironically, both teachers agreed with the two physics teachers that the student's objection was justified. However, the reason for the same response was very different.

The third biology teacher interpreted the student's objection in accordance with the expectations that led to the design of the incident: he thought the student was objecting because the student believed work in should be greater than work out. He confronted the student, telling him that was wrong.

> I would ask him, "Well, wait a minute, the idea behind a system is to make work easier, is it not?" And then I'd throw it back to the class and say, "What do you think guys? I mean why even develop a pulley system?" And I'd give them an example of a pulley system. I'll say "In my barn I have my camper on a truck. I try to lift it off and hang it. There was no way I could do it. There were five people [. . .], we could not do it. But I bought a cheap pulley system, attached to the top of my barn, hooked it to the camper shell, and I alone could just pull the thing up."

The responses of the teachers to the fourth type of incidents, those that portrayed general class difficulties, showed that, at least in the physics cases, the more knowledgeable teachers were more likely to effectively deal with these difficulties.

In summary, knowledgeable teachers were more likely to detect student preconceptions, to exploit opportunities for fruitful "digressions", to deal effectively with general class difficulties, and to interpret correctly students' insightful comments. The physics incidents indicated

that the unknowledgeable teachers might actually reinforce preconceptions, incorrectly criticize correct student answers, and accept faulty laboratory results. The biology incidents indicated that in some cases even relatively knowledgeable teachers would lack the knowledge necessary to effectively ceal with student difficulties.

Explanatory Representations

The teachers' responses were also analyzed for the knowledge representations, such as examples and analogies used by the teachers. The knowledgeable teachers tended to use more explanatory knowledge representations, but the larger number reflected their richer non-topic disciplinary knowledge. While planning, both groups of teachers used almost the same number of representations of topic knowledge.

However, the representations used by the two groups and the way they were discussed reflected differences in understanding. Biology teacher BA, for example, used a number of representations while discussing the lever topic. However, she discussed all the examples--the body joints, lifting a car, building cranes, construction work, building the pyramids--to show that machines are useful. Physics teacher PB, in contrast, used one example, the arm, very differently. He discussed a situation where somebody holds a weight at arm's length to discuss the huge force that would be exerted by the arm's muscles, and to illustrate the balance of torques.

Finally, the representations were found to reflect teacher preconceptions and knowledge inaccuracies. The case of the biology teacher who used the example of the pulley system in his barn as an illustration of the preconception that "machines decrease work" was discussed earlier. Explanatory representations are powerful tools. They can enhance the

understanding of both science conceptions and preconceptions.

DISCUSSION

In the first part of the study we found that knowledgeable teachers had more detailed knowledge of their topic, more knowledge of other discipline entities (whether these be other discipline topics or concepts or high-order concepts, principles, and conceptual schemes), and more knowledge of ways of relating the topic to other discipline entities. We, later traced the effects of these knowledge differences on teacher planning and simulated teaching. Teacher prior subject-matter knowledge and approach affect different aspects of the transformations of the subject matter found in textbooks while teachers are planning. Some of these transformations occur indirectly through the use of activities and other representations of knowledge. If teachers follow their plans, (and there are many reasons to believe that teachers generally do follow their plans), this transformed subject-matter would be presented to the students. Analysis of simulated teaching revealed that teachers would reinforce this transformed subject-matter through their evaluations and through their responses to classroom critical incidents.

The study began with the question, how does teacher knowledge of subject-matter affect teaching? The results presented above describe empirical findings that describe these effects. The analysis, however, produced other results which are probably as important as the empirical findings. It provided a set of concepts for describing and studying teacher knowledge of subject-matter and its effects. These include categories for describing subject-matter knowledge such as knowledge of topics, knowledge of basic discipline entities, and knowledge of approaches. They also include categories for describing the transformations that occur in subject-matter such

as the direct transformations of subject-matter content and organization, or the indirect transformations that occur through the use of activities and other representations, or the reinforcement of these transformations through the evaluative structure and responses to critical incidents that occur while teaching. These last categories lead to a better description of the effects of subject-matter knowledge. The study leads us to view prior teacher knowledge of subject matter as greatly contributing to the transformation of the written curriculum into an enactive curriculum, a transformation that starts during preactive teaching and is reinforced and completed during interactive teaching.

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APPENDIX A

Physics Knowledge Schemata

PA

Lever:

1. Parts: fulcrum: point around which rotation occurs

   arms: effort arm
   resistance arm

2. Applied forces: effort
   resistance

3. Constraint: effort and resistance define effort and resistance arms lengths

4. Lever as object under forces: if $F_1r_1 = F_2r_2$

   i.e., clockwise torque = counterclockwise torque, balance occurs

5. Lever as machine: three classes:

   First class: description: (?)
   function: (?)
   example: teeter-totter

   Second class: description: (?)
   function: mobility
   example: arm, catapult

   Third class: description: (?)
   function: [Mechanical Advantage]
   example; nutcracker

APPENDIX B

Biology Knowledge Schemata

BA

Photosynthesis

1. Photosynthesis = light cycle (!)

2. Function: Trapping energy in chemical bonds

3. Input: Light energy

   CO_2

   H_2

4. Needed: chloroplast
   energy-carrying molecule

5. Output: glucose (chemical energy)
   oxygen (waste product)

6. Description: Attaching molecules to one another and trapping energy in chemical bonds.
   $NADPH^+$ involved

7. Occurs: in chloroplasts in usually green plants
   mostly at sea

8. Only specific wavelengths of light needed